SOVERHILL

The use of Alchol in
Internal Conbustion Engines

Graduate School

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THE USE OF ALCOHOL IN INTERNAL COMBUSTION ENGINES

BY

Harvey Allen Soverhill, B.S., 1900

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HARVEY ALLEN SOVERHILL, B. S.

ENTITLED THE USE OF ALCOHOL IN INTERNAL COMBUSTION ENGINES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Mechanical Engineer

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Introduction.

The past five years have shown a remarkable increase in the output of gasolene engines, more, particularly the smaller sizes. The field of usefulness and diversity of application of the gasolene engine is doubtless greater than that of any other source of power. It has a most extensive and promising future. It becomes a question of the most vital importance when we consider the fuel requirements for the engines of a rapidly growing automobile industry in addition to the annual output of over one hundred thousand gasolene engines. It is plain to see that some fuel must be found that has a low cost of manufacture and an unlimited source of supply. Up to the present date the only ideal rival of gasolene has been ethyl or grain alcohol.

The reports of the United States Geological Survey all lend strength to the belief that the supply of petroleum is fast becoming exhausted. The surveys show that while the oil fields are widely distributed, they are very limited in extent. The average percentage of gasolene in petroleum from all the oil fields in the world is less than two per cent. This fact, taken in connection with the constantly increasing demand and failing supply, makes it necessary to find a fuel that has unlimited possibilities of production.

The greatest obstacle to the progress of the alcohol motor development is the fact that in most countries alcohol is regarded as an extremely potent intoxicant and its manufacture is accordingly restricted by a heavy tax. Since alcohol in its pure form is subjected to this tax, it follows that the portion of the

product designed for industrial uses, and on which no excise duty
is to be levied, must be rendered unfit for use as a beverage. The
term "denaturalization" is given to this process, and it consists
essentially in mixing methyl or wood alcohol, or other noxious
substances, with grain alcohol, usually designated as spirits of
wine or ethyl alcohol. It is highly important that the denaturant
selected, to be satisfactory, first,must be very difficult to
separate from the mixture; second, must not interfere with the use
to which the alcohol is to be applied; and third, its cost must
be such as to not appreciably increase the price of the final
mixture. The purpose for which the alcohol is to be used determines
the character of the denaturizing agent employed and is under the
sanction and surveillance of the respective governments.

Relative Calorific Values.

It is usually explained that the reason alcohol was taken
up as a motor fuel so much later than the petroleum products was
that scientists had condemned it untried on account of its low
calorific value.

Alcohol has much less heating capacity than an equal
weight or volume of benzine, but it is, after all, not alcohol nor
benzine that is burned in an internal combustion motor. It is a
mixture of alcohol vapor with air or a mixture of benzine or
gasolene vapor with air. The working efficiency of the motor
depends more upon the calories contained in the explosive mixture
than upon those in the liquid from which the mixture is derived. It
depends also upon the completeness of the combustion and other
factors.

Two kinds of alcohol are under consideration; ethyl alcohol

or spirits of wine, of which the chemical radicals are C_2H_5HO,
a potable inebriating liquid of 0,795 specific gravity, at a low
cost of production but taxed in this country $2.08 per gallon
"commercially pure" (94 to 95 per cent); the other, methylic
alcohol, or wood spirits, chemical radicals $C H_3 HO$, a poisonous
liquid of slightly lower specific gravity with a cost of production
probably twice as high as that of ethyl alcohol but tax free in the
United States.

Wood alcohol has fewer heat units than grain alcohol and
a more pungent odor, due mostly to the presence of methylic ether.

Maximilien Ringelman finds that 90 degree alcohol dis-
engages 6045 calories by combustion under constant pressure, and
6056 when under constant volume; and that 90 degree methyl alcohol
yields 4594 calories per kilogram either way.

In many cases alcohol containing 25 volume per cent of
water (equal to 29.6 per cent weight, owing to its higher specific
gravity) has been used in stationary motors in Germany with satis-
factory results. This 75 per cent alcohol has a specific gravity
0.846, contains only 4380 calories per kilogram or 3710 per liter,
while kerosene contains 10000 per kilogram and 8000 per liter,
benzine 10000 per kilogram and benzol 9700 per kilogram. Absolute
ethyl alcohol contains 6480 calories per kilogram or 5166 per liter.

The following table is of the highest importance for
showing why alcoholic fuel, in spite of its low heat capacity, will
produce amounts of mechanical work in a motor larger than have
been obtained with richer fuels in the same motor or a motor of
the same cylinder volume or piston displacement.

	1 KG. CONTAINS			1 Kg. vapor occupies cu. meters	1 Kg. requires for complete combustion cu.meters of air.
	C.	H.	O.		
Wood Alcohol $C\,H_3HO$	0.375	0.125	0.500	0.697	5.042
Ethyl Alcohol C_2H_5HO	0.522	0.130	0.348	0.485	7.015
Benzine C_6H_6	0.923	0.077		0.286	8.273

Benzine has been selected to represent kerosene and
gasolene, being the liquid of most stable composition in this class.

We see here that a kilogram of benzine vapor, together
with the air theoretically required to burn it occupies 8.559
cubic meters, while the same eight of ethyl alcohol vapor mixed
with air occupies only 7.5 cubic meters. In one case we have 10000
calories in 8.559 cubic meters; in the other 6480 in 7.5 cubic
meters. Equalizing the volume, the proportion between calories
from benzine and calories from alcohol is no longer that of 10000
to 6480, but only 8760 to 6480; or, in other words, a cylinder full
of combustible alcohol vapor mixture contains almost exactly three-
fourths as many calories as the same cylinder full of benzine
vapor mixture, which is a considerable gain from the proportion of
calories in the liquids.

With wood alcohol the proportion grows even much more
favorable, giving 6705 calories for benzine corresponding to 5104
for wood alcohol; or, a cylinderful of vapor mixture from methylic

alcohol contains more than three-fourths as many calories as a cylinderful of benzine vapor mixture. This seems to open up certain possibilities for using wood alcohol alone, provided it is purified of the acetone which crops out in the exhaust as acetic acid and corrodes valves, and provided the price of the purified product may be brought within reach.

It is, of course, due to the oxygen (hydroxyl) contained in the alcohols that so much less air is required for its explosive combustion, making it possible to introduce relatively more vapor in each charge, but it should be remembered that this oxygen is paid for, while the oxygen used for burning benzine vapor is free for the taking. So far as anything yet said is concerned, the relative economy of the fuels is not affected, but the question of technical efficiency is of course deeply involved. Especially for use in automobiles it is of the highest importance that the lower calorific value of alcohol is offset by the ability to use more of it with a given motor. This also bears strongly upon the question of interchangeability of the fuels, in its favor. But for this factor it is more than doubtful if automobiles operated with carburetted alcohol in the French and international races could have held their own as they did.

The presence of oxygen and the excess of hydrogen in alcohol vapor, causing its smaller specific gravity (larger volume) and the greater kinetic velocity of its molecules by which its complete and intimate mixing with air is facilitated, have undoubtedly much to do with one of these factors, which consists in complete combustion (and odorless exhaust) of the explosive charge. Complete combustion is the rule when alcohol is the fuel and the

exception with the liquids containing no oxygen.

The other factor leading to avoidance of waste or high
thermic efficiency is the possibility of a very high compression
in the alcohol motor, due partly to the low inflammability of the
alcohol vapor, and furthermore to the aqueous vapors mixed with it
from the water contained in the alcohol. High compression is not
only an advantage of the alcohol motor but also a necessity, being
required to counteract the slow inflammation which alcohol vapor
has in common with kerosene vapor but not with benzine or gasolene
vapor.

With regard to the causes for the complete combustion,
L. Perisse and H. de la Valette are responsible for an experimental
determination of great value. They find that the proportions in
a 90 degree alcohol vapor mixture which admit of complete combus-
tion in an explosion motor vary from 1 of vapor with 10 of air to
1 of vapor with 25 of air, while the proportions for 90 degree
alcohol mixed with an equal volume of benzol vary only from 1 of
vapor with 41 of air to 1 of vapor with 52 of air.

In order to get closer to the question of how much power
can be gotten out of a motor using alcohol compared with a benzine
motor of the same dimensions, a few mathematical calculations will
prove interesting. Sorel states that the theoretical amount of
air required for burning 1 kilogram of denatured 90 degree alcohol
is 6 cubic meters and for 1 kilogram of essence or gasolene 11.85
cubic meters. But if good combustion can be secured under all
conditions, the theoretical amount of air, he finds, must be
multiplied by 1.3 to 1.7 (the variation depends mainly on tempera-
ture.)

Using the approximate figures for the space occupied by 1 kilogram

of pure denatured alcohol vapor and 1 kilogram of pure gasolene

vapor and multiplying the theoretical air requirement in both cases

by 1.5, we find that the explosive and thoroughly combustible mix-

ture formed from 1 kilogram of 90 degree denatured alcohol occupies:

$$0.485 + 9 = 9.485 \text{ cubic meters,}$$

containing 5923 calories, while the explosive and thoroughly com-

bustible mixture formed from 1 kilogram of gasolene occupies:

$$0.286 + 17.775 = 18.061 \text{ cubic meters,}$$

containing about 10500 calories.

Again reducing to equality of volume

$$\frac{18.061 \text{ meters}}{10500 \text{ calories}} = \frac{9.485 \text{ cu. meters}}{X}$$

giving X = 5514 calories, or, a thoroughly combustible gasolene

vapor mixture contains 5514 calories, as against 5923 calories

in an equal volume of thoroughly combustible 90 degree denatured

alcohol vapor mixture.

While these rather surprising figures are subject to what-

ever minor changes may arise from exact knowledge of the specific

gravity of the two vapors under consideration, some stress has been

laid on the high calorific value of each explosive charge derived

from alcohol, because it has not been referred to elsewhere, and

because

1, - It explains why automobile motors designed for gasolene

may be operated without sensible power reduction, by sacrifice of

fuel economy, and

2, - It promises that automobile motors, if designed specially

for alcohol, so as to get the benefit of the high thermic efficiency

accomplished in stationary alcohol motors, will be more compact, for any given power, than our present gasolene motors, and

3, - The dynamic efficiency of an alcohol motor is of special importance in a country like the United States, where an abundance of cheap rich lands renders it probable that alcohol may be produced so cheaply, once the tax is removed, as to take the edge off the question of economical efficiency in favor of other considerations.

It seems worth noting in the figures pertaining to this matter that the volume of air required for the combustion of 90 degree alcohol vapor is less, according to Sorel, than for the combustion of the vapor from absolute alcohol, and that the minimum proportion of 10 air to 1 vapor arrived at by Perisse and Valette are in accordance therewith, so that we may infer that the 10 per cent of water actually assists in securing combustion, when other conditions are right, besides serving the purpose of permitting higher compression and a higher thermic efficiency, as further detailed hereafter.

With regard to gasolene, on the other hand, if the range for air admixture by which perfect combustion may be secured should prove as narrow as suggested by Perisse and Valette's figure - 1.3 to 1.7 times the theoretical volume of air - should not be admissible, this would in practice mean only that a gasolene vapor mixture would usually lose by partial non-combustion what it gained in number of calories for a given cylinder volume.

Especially in automobile practice, where high operative skill cannot be the rule, the wide variation of the amount of air admixture admissible with alcohol as fuel, should mean a gain in

the economical as well as in the dynamic efficiency of a motor.

Regarding the question of thermic efficiency, or the determination of how well the alcohol motor utilizes the calories fed to it, transforming them into mechanical work, we find that Prof. W. Hartmann, as early as 1894, reported to the German Agricultural Society that a stationary petroleum motor operated with alcohol gave excellent power results but used far too much alcohol. Dynamically, the fuel was a great success, economically a flat failure. Special regulation of compression, ignition and carburation in conjunction with lower alcohol and higher petroleum prices have changed the latter half of this verdict; the special regulations bringing about an increased utilization of the calories, offsetting the larger amount of the liquid fuel used for each explosion (as compared with gasolene in a motor of similar dimensions.)

An account of what becomes of the calories introduced in the gasolene motor shows strikingly how readily we should be willing to expect more thermic efficiency from another fuel. In the French tests in 1902 its thermic efficiency frequently did not exceed 14 per cent, ranging from this to 20 per cent; and in a few rare cases touching 25 per cent; and this under test conditions.

From another source it is reported that in the accepted type of automobile motors the utilization of the calorific energy varies from 15 to 20 per cent.

Representing the number of calories which are liberated by complete combustion by 100 we have:

        Calories wasted in exhaust-------------27
        Calories lost by radiation and otherwise 9
        Calories carried away by cooling water--48
        Leaving at disposal for work --------- -16

In a series of tests made by the writer in 1900 at the

University of Illinois on a 10 horse-power Otto engine, the

energy was found to be distributed as follows:

        Wasted in exhaust ------------------20.98
        Wasted in radiation, etc.,--------- --12.51
        Carried away by Jacket water-------45.15
        Leaving for work-- --------------- -21.36

At the comparative tests held in Berlin in 1902 and

reported by Dr. E. von Mayer, the highest thermic efficiency

obtained for benzine motors was 20.6 and for kerosene 18 per cent.

Similar trials were conducted in 1903 for the Austrian minister of

Commerce by L. Erhard with two 8 horse-power motors giving 16.5

per cent caloric efficiency for benzine and 28 per cent for 90

degree alcohol.

From two special types of petroleum engines better

efficiencies were obtained however. The Banki motor, made by

Ganz & Co., of Buda-Pesth, when exhibited at Vincennes in 1900

gave a 28 per cent thermic efficiency, obtained by the injection

of 2.205 pounds of atomized water per horse-power - hour, the

injection being made during the compression stroke. The compres-

sion was 234.2 pounds per square inch. The Diesel motor with its

enormous compressions (above 700 pounds per square inch) and liquid

fuel injection commencing at the end of the compression stroke,

has given still higher percentages in various tests. While these

results may point the way toward increased economy with petroleum

fuels for certain forms of work where neither the complication of

water injection nor massive design is objectionable, the comparison

for alcohol motors must of course be made with petroleum or benzine
motors of the designs accepted for general purposes in the power
market.

The crux of the comparison is indeed as much to ascertain
in what manner the special properties of alcohol lend themselves
to ready and convenient utilization for power purposes, as to
determine the exact economical relations.

Of ten alcohol tractor engines entered for a prize
competition in the Berlin trials (1902) one gave a thermic effi-
ciency of 32.7 per cent, and two others above 30 per cent, all with
German denatured alcohol. At the French trials the same year the
results with denatured alcohol (containing 8.55 per cent wood
alcohol) were not uniformly so good, but Gustave Chauveau reports
one case where the thermal efficiency was even better, reaching
38 per cent, being considerably higher for the 90 degree alcohol
than for carburetted (50 per cent benzol) mixture in the same
motor, which was a 16 horse-power Brouhot running at 180 revolutions
per minute. It is said that there were no real alcohol motors at
these trials, but only gasolene engines regulated to burn alcohol.
It was observed that the conditions which produced the most
economical results were high compression, long stroke, small number
of revolutions per minute and 140 pounds compression for 90 degree
alcohol. Under half load the efficiency always fell to much lower
figures, in about the same proportions as with gasolene and
generally lower than in the German trials, it seems, altho
hit-and-miss governing was until then commonly employed in French
stationary motors, and should give a higher fuel economy than the
throttling system now used almost exclusively in the German

stationary tractor alcohol engines.

Reverting to the German trials, we find that the three prize winners in the tractor engine competition consumed alcohol per horse-power-hour as shown in the following table:

	Full Load Grams alcohol per horse-power-hour	Normal Load Grams alcohol per horse-power-hour
The Deutz Engine	365	389
The Marienfelde	352	397
The Durr	384	412

This same table expressed in gallons per horse-power-hour by using the weight of one gallon proof spirits as 7.68 pounds or 122.88 ounces and 1 gram as 0.0527 ounces, viz:

	Full Load Gallons alcohol per horse-power-hour	Normal Load Gallons alcohol per horse-power-hour
The Deutz Engine	.1566	.1661
The Marienfelde	.1509	.1702
The Durr	.1646	.1767

This is mainly of interest as showing a considerable variation in the decrease of efficiency as the load is reduced, the Durr showing the smallest loss, probably by reason of smaller frictional wastes in its operation. In the Deutz engine no carburettor is used and the spray of alcohol is drawn into the cylinder only during the last half of the suction stroke, apparently on the original Otto theory of stratification, but possibly to avoid "splitting" of the alcohol resulting in formic aldehyde and soot

deposit in the motor. The consumption of the Deutz engine corresponds to a thermic efficiency of about 32 per cent. The same firm makes benzine and kerosene engines and all these three types give in a comparative test the results shown in the following table.

	Alcohol		Benzine		Kerosene	
	Grams used per H.P.hour	Cost Pfennig	Grams used per H.P.hour	Cost Pfennig	Grams used per H.P.hour	Cost Pfennig
Full Load	·365	7.3-7.6	297	7.1	330	7.3
Half Load	507	10.1-10.6	434	10.4	492	10.8

With small motors of about 3/4 horse-power and 600 revolutions per minute, the consumption was found to run up to 750 grams per horse-power-hour at full load. At the time of these trials little had been done to adapt automobile motors to alcohol, and the data in regard to them are therefore not at all conclusive, but it may perhaps be assumed that their efficiency would lie between that of the small 3/4 horse-power and that of the slow speed tractor engines of about 10 horse-power referred to in the above figures.

Prof. Meyer calculates that at a price of 20 marks per 100 kilograms alcohol (90-degree denatured), 24 marks for benzine and 22 marks for kerosene, the economy of the three fuels would be about equal, while at present the benzine motor shows a slight superiority under full load in spite of the higher thermic

efficiency of the alcohol, 1000 calories derived from alcohol cost-
ing 3.64 pfennigs, as against 2.33 pfennigs for 1000 benzine
calories and 2.14 pfennigs for 1000 kerosene calories.

Accepting the proportion in these figures, we infer that
the price of 15 cents per gallon of 90-degree alcohol would place
this fuel economically on a par with gasolene at 18 cents per
gallon, for stationary and slow speed portable motors, the latter
including most Marine motors, while the question of economy for
automobile motors would still remain in abeyance pending further
developments. 180 to 250 revolutions per minute are,it seems, the
highest motor speeds in the alcohol motors for which high thermic
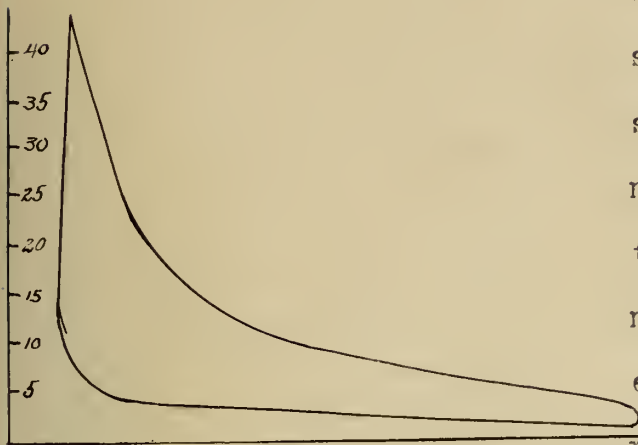and economical efficiency was recorded.

At the Congress convened in Paris, 1903, to record the
data and desiderata in regard to the industrial applications for
alcohol 1500 members were present, and they resolved that 90-degree
alcohol must be sold for about 20 cents per gallon before it would
be competitive with high grade gasolene. Mr. Chauveau calculates
that at 20 cents for denatured alcohol and 28 cents for benzol-
alcohol, both these fuels would have an economical superiority
over gasolene at 40 cents per gallon in the relation of 350 to 140
and over kerosene at 32 cents in the relation of 350 to 200.
These figures are based on a thermic efficiency of 38 per cent for
the best stationary slow speed alcohol motor.

High compression and complete combustion furnish almost
the entire explanation for the high thermic efficiency obtained
with alcohol. Long stroke, while necessary for the highest
efficiency in somewhat greater degree than for gasolene, but
probably not as much as for kerosene, forms a factor whose import-

ance depends greatly upon the degree of compression and the composition and temperature of the explosive mixture when fired, these being the principal elements influencing the rapidity of flame propagation with any given fuel. This being the case, the data for determining the best length of stroke·are , as yet, too complicated with other factors to permit establishing a practical comparison with gasolene on this point.

A rather important question arises in connection herewith. It has been commonly believed that the combustion of alcohol vapor (also kerosene vapor) was much slower than that of gasolene, the relations being supposed to parallel with those between prismatic slow-burning powder and fine-grained gunpowder. Under this supposition we should expect rapid ignition of the whole mass of alcohol mixture followed by a relatively prolonged combustion, rendering a long stroke as much of a requirement for efficiency as is a long bore for a heavy cannon. We know that ignition plus combustion requires more time with alcohol than with gasolene,under equality of compression, temperature and ignition method. If the delay is due to slow flame propagation and may be overcome by higher compression and other available means, it is possible that nearly "square" design may be as well adapted for alcohol as for gasolene. A glance at the indicator card of a highly efficient alcohol explosion would seem to support this theory, the sudden drop from highest pressure presenting small probability of a sustained combustion, while the slight departure from the perpendicular of the explosion line indicates that the ignition was not instantaneous in spite of the very high compression of 10 1/4

atmospheres.

     In the gasolene motor, compression is strictly limited by the danger of premature ignition, seldom exceeding 75 pounds per square inch, while the low infla,- mability of alcohol exphasized by the presence of water in this fuel makes it possible to obtain an explosion pressure of 43 atmos- pheres by increasing the compres- sion to nearly twice the maximum used for gasolene. But the same properties of hydrated alcohol also mean that the conditions for igni- tion are more exacting than for gasolene, this resulting in diffi- culties when it is desired to start a cold motor with this fuel.

Compression 10 1/4 atmospheres-
Explosion pressure 43 atmos-
pheres.

     Compared with gasolene, alcohol requires 2 1/2 times as much heat to effect vaporization, and the water in it requires 5 times as much per weight unit. The heat must either be more intense or be sustained longer. The latter is preferable in order to obtain a homogeneous mixture, but no so practicable. Sorel has determined the relations for the French fuels, stating that one kilogram of 90-degree denatured (methylated) alcohol absorbs 288 calories in its evaporation; carburetted alcohol (half benzol) 196 calories and benzine 120 calories. Remembering that the volume of air required in the mixture is much smaller in proportion to the volume of alcohol vapor to be generated by it and mixed with it than with gasolene, we are not astonished to find from the records

of experiments by Sorel that, if condensation is to be avoided, the mixture must at no time be below 26 degrees Cent.(78.8 degrees F.) with the minimum amount of air, while it may go down to 22 degrees Cent.(71.6 F.) if 1.3 times the minimum of air are used and to 17 degrees Cent. (62.6 F.) if 1.7 times the minimum of air is used. This of course has a strong bearing upon the start of the motor with alcohol in cold weather and also upon subsequent operation, and accordingly we find in descriptions of carburettors that provisions are made for heating at both air intakes and that the neutral air intake is little used and in in some carburettors is even absent, all the air possible being needed for evaporative effect.   Operating in an atmosphere fully charged with humidity at 15 degrees Cent.(59 F.) Meyer finds that a temperature of 190 degrees Cent. (374 F.) is required to prevent suspension of liquid fuel in the mixture, but with excess of air he, too, finds that the need of high temperature decreases, so that a temperature of 125 degrees Cent. (257 F.), for example, was sufficient to carry the vapor in that motor in the Berlin trials, which showed the greatest efficiency with the poorest mixture.   In general, the best effect was obtained from a cool mixture heated by high compression, as with gasolene motors.   These facts explain the statement made previously; that with alcohol high compression is not only the great advantage which produces high caloric efficiency, but is also a necessity.

The conditions for successful operation which relate to temperature are narrower than with gasolene, but when complied with the combustion is much more perfect.

This somewhat delicate equilibrium of temperature which

must be maintained in order to get the full benefit of the possi-
bilities of the fuel is instanced by Fehrmann, who showed that
twice as much alcohol was required to drive a motor (on half load)
when the cooling water was kept at 15 degrees Cent. (59 F.) as
when the cooling water was 100 degrees Cent. (212 degrees F.)

It has also been shown that the best cooling system for
fuel economy with a large stationary alcohol motor consists in
connecting the jacket ot surrounding the cylinder with an open
tank, without any forced circulation, but in which the water is
kept between a low and a high level by periodical additions of
water at about 100 degrees Cent.

When a Hit-and-Miss governor is used, there is a notable
falling off in the strength of explosions after each cut-out, owing
to the cooling of the cylinder walls in the interim. The effect
is shown graphically in the reproduced
card showing the first seven succes-
sive explosions after a brief stop
of a gasolene motor and is said to be
even more pronounced with alcohol. In the first one the inflamma-
tion is distinctly slow and not till the seventh is there a return
to the full capacity of the engine.

With all of this sensitiveness to temperature, it should
not be forgotten that the Deutz engine with spray injection at
the middle of the suction stroke is highly efficient.

There is little doubt that the alcohol engine will
eventually be operated without recourse to gasolene for starting,
or heating a carburettor by exhaust gases, jacket water or lamp,or
by the injection of finely atomized alcohol near the end of the

compression stroke, relying solely on the compression for producing
the necessary heat.

During the first few years when alcohol motors were tried,
valves and valve seats were frequently found affected by rust, and
soot deposits were also observed in the combustion chamber. Acetic
acid ($C_2H_4O_2$) was found in the exhaust, indicating the cause of
the rust. The difficulty was due to the splitting of the radicals
into new combinations under the effect of too great heat in the
vaporization methods, or not enough heat, causing the suspension
of accluded water in the mixture, which led to the formation of
formic aldehyde (CH_2O), and again to acetic acid by the incom-
pleteness of the combustion. This serious objection has been al-
most completely overcome by the use of improved carburettors
vaporizing the alcohol and water thoroughly before entering the
cylinder. In high speed engines the best results have been obtain-
ed by injecting the alcohol as a finely atomized spray and depend-
ing upon the heat of the cylinder walls and the compression to
effect the vaporization. As with kerosene, the shorter the time
elapsing between the transformation of the fuel from a cold liquid
to a gas mixed with air and its combustion, the better is the
guarantee against the formation of incombustible compounds.

The rust and soot trouble needs careful attention especial-
ly in automobile motors in which throttling means reduced compres-
sion. Ignition at low compression means slow inflammation of a
mixture probably insufficiently vaporized, and this of all things
is to be most avoided with alcohol.

In the very nature of alcohol there seems, however, to be

a remedy, which should at the same time obviate the danger of soot
and rust and increase the motor's efficiency under the light loads
which are the normal loads in automobile practice. The wide range
of air admixture (from 10 to 25 volumes of air for 1 of vapor)
under which alcohol vapor retains its complete combustibility is the
redeeming feature. It would be easily possible to devise a thrott-
ling arrangement based on a scale of reduced vapor admissions,
synchronized with a scale of increasing air admissions; but, it
has not been done yet. Nevertheless, the perfect adaptation of
alcohol to automobile requirements would seem to depend on such
an arrangement, substituting variable composition entirely for
variable compression and constant composition.

One of the most promising features of the alcohol motor
for automobile purposes is undoubtedly the very effective internal
cooling caused by the absorption of heat in converting the water
in the alcohol into superheated steam, a process which serves the
transmutation of heat into work doubly: adding directly to the
power by steam expansion and obviating the excessive waste now
taking place thru the necessity of energetic external cooling by
forced circulation of water. It is only thru such a resource that
we may expect to escape the very considerable incumbrance of the
automobile which the external cooling system involves, while saving
the metal of the motor in some measure against the deteriorating
effects of rapidly successive expansions and contractions and im-
proving the lubrication. The process is distinctly the most
practical one in line with the efforts that have been made for
combining the steam and the explosion engine, and the simplicity of
this process depends upon that quality of alcohol that it is

miscible with water, while kerosene and gasolene will not absorb
water, and at low temperature will expel an alcohol admixture if
left at perfect rest as in the reservoir of a lamp.

Homogeneous Fuel.

In considering the different fuels, the subject of the
physical nature, - the homogeneous nature, ought not to be over-
looked. Ordinary gasolene, as sold, is a mixture of hydrocarbons
commencing with one known to chemists as pentane, so called because
having five atoms of carbon, and going up to molecules having
nine and ten. This is a description which will probably be inter-
esting only to those who are chemically educated and such persons
are referred to the boiling point curves carried out by Mr. Lester
of the Chamber of Commerce Testing House at Manchester for other
evidence of this variation.in composition.

If you start to heat up a liquid like water, and put a
thermometer in it, and notice the temperature at which it begins
to boil, you will find that it begins to boil, for instance, at
100° C. and that it will go on boiling at 100° C. until it is all
gone. This is because water is a homogeneous substance. If we
take a mixture such as gasolene, we shall find that it begins to
boil at about 80° C, and some of it goes over, then the thermometer
goes on rising and rising, and does not finish rising until
practically the whole of the liquid has gone over, and you will
find the temperature to be as high as 222° C, which is an actual
temperature recorded by Mr. Mr. Lester on a sample of gasolene.
That is to say, it consists of a mixture of organic compounds, some

of which boil at 80° C. and others at over 220° C. A fuel made of
a mixture of things like this, all having different properties, all
being differently volatile, having different boiling points, is a
long way removed from being an ideal fuel. It is the case that
pure gasolene boils at somewhere about 80° C. but crude gasolene,
such as we have to use owing to the restrictions of supply and
price, boils at anywhere from 80° C. to 200° C. Alcohol is a
chemically homogeneous substance; like water, it starts to boil
at a certain temperature, and it finishes boiling at the same
temperature, about 80° C. Alcohol suits what we consider ideal
conditions far more completely than gasolene, benzine or naptha.

<div align="center">The Cost of Alcohol</div>

is determined in a measure by the product from which it is made.
The Germans use potatoes principally,while the French use beet
roots. In the West Indies and South America, the refuse in the
manufacture of sugar is employed. In Germany, the price of denatur-
ed alcohol ranges from 13 1/2 to 16 cents per gallon for 50 gallon
lots, the denaturant used determining the cost.

It is stated in the March number of Power, 1901, that a
New York distiller produced alcohol at a cost of 8 cents per
gallon. It was sold in New York in car-load lots at $2.26. The
tax is $2.08 per gallon, which leaves 18 cents to cover cost of
production, profit and risk of tax.

In the report of Platt and Russell, page VII of the Joint
Select committee appointed to report on the advisability of removing
the tax on industrial alcohol, distillers testified that the cost
of production was 8 1/2 cents per proof-gallon. Other distillers
claim that from 40 cent corn,it can be manufactured for 13 1/2 cents

per gallon of 94 per cent strength.

Alcohol has been made in France from acetylene at a cost of 15 cents per gallon, and it was estimated that if the calcium carbide used in its production was manufactured at the same place, the cost could be reduced by this method to 8.7 cents per gallon.

At a recent meeting of the Americal Chemical Society at New Orleans, facts were developed to show that because of the immense bi-products from the sugar industry in the shape of crude molasses, alcohol could be manufactured from such sources at an actual cost of from 10 to 11 cents per gallon, and that it could be sold at a good profit, both in sugar and corn producing regions, at a cost of from 18 to 22 cents per gallon.

In Cuba, Peru, Brazil and other sugar producing countries, the alcohol is manufactured from the waste products, and hence very cheaply produced. The present price in Cuba is about 10 cents per gallon.

It is thus seen that alcohol can successfully compete in price with gasolene, which now sells for from 12 to 22 cents per gallon.

"Denaturized" alcohol.

For most industrial purposes alcohol is used in Germany duty free, after having been "Denaturized" or rendered unfit for drinking purposes, by admixture, in presence of a government official with a prescribed percentage or proportion of one or more of several different substances prescribed in the very elaborate statute which governs that complicated subject in this country. There are two general classes or degrees of denaturizing, viz: the

"complete" and the "incomplete" according to the purpose for which the alcohol so denaturized is to be ultimately used.

German Methods of Denaturizing.

1.- Complete denaturization by the German system is accomplished by the addition to every 100 liters (26 1/2 gallons) of spirits:

(a) Two and one-half liters of the "standard denaturizer" made of four parts of wood alcohol, one part of pyridin (a nitrogeneous base obtained by distilling bone oil or coal tar) with the addition, of 50 grammes to each liter, of oil of lavender or rosemary.

(b) One and one-fourth liters of the above "standard" and two liters of benzol with every 100 liters of alcohol.

Of alcohol thus completely denaturized, there was used in Germany during the campaign year 1903 - '04, 931,436 hectoliters denaturized by process (a) as described above and 52,764 hectoliters which had been denaturized by process (b). This made a total of 26,080,505 gallons of wholly denaturized spirits used during the year for heating, lighting and various processes of manufacture.

2.- Incomplete denaturization- i.e. sufficient to prevent alcohol from being drunk, but not to disqualify it from use for various special purposes for which the wholly denaturized spirits would be unavailable- is accomplished by several methods as follows- the quantity and nature of each substance being the prescribed dose for each 100 liters (26 1/2 gallons) of spirits.

(c) Five liters of wood alcohol or one-half liter of

pyridin.

(d) Twenty liters of solution of shellac, containing one part gum to two parts alcohol 90 per cent purity. Alcohol for the manufacture of celluloid and pegamoid is denaturized, -

(e) By the addition of one kilogramme of camphor or two liters of oil of turpentine, or one-half liter benzol to each 100 liters of spirits. Alcohol to be used in the manufacture of ethers, aldehyde, agarcin, white lead, bromo-silver gelatins, collodion, salicylic acid and salts, aniline chemistry and a great number of other purposes, is denaturized by the addition of -

(f) Ten liters sulphuric ether or one liter of benzol, or one-half liter oil of turpentine, or 0.025 liter of animal oil.

For the manufacture of varnishes and inks, alcohol is denaturized by the addition of oil of turpentine or animal oil, and for the production of soda soaps by the addition of one kilogramme of castor oil. Alcohol for the production of lanolin is prepared by adding five liters of benzine to each hectoliter of spirits. The whole amount of incompletely denaturized alcohol of the several grades above described which was consumed in Germany last year was 385,946 hectoliters or 10,227,569 gallons. In addition to all the foregoing, 21,799 hectoliters of alcohol were used duty free and without denaturization of any kind for governmental or public purposes such as hospitals, government labratories, and for the manufacture of fulminates and smokeless powder.

ALCOHOL FROM SAWDUST.

A highly promising process for utilizing saw-mill refuse has been developed by Prof. Alexander Classen, of the Aix-la-Chapelle Technical High School, in Germany. As the tests made in the experimental plant have given satisfactory results, an industrial plant where alcohol is produced from sawdust on a large scale has recently been erected in this country.

The production of glucose or sugar from cellulose, and its eventual conversion into alcohol, is a process by no means novel. In fact, this was done by Mr. Braconnet as early as 1819, by treating the cellulose with heated sulphuric acid. The sulphuric acid, however, being a liquid, could not be removed from the resulting solution without great difficulty, and only at an expense which rendered the process impracticable for industrial purposes.

Prof. Classen conceived the idea of using, in place of the liquid sulphuric acid, gaseous sulphurous acid, as this will readily escape on the application of the moderate heat, thereby leaving the treated wood practically free from any substances liable to prevent fermentation of the sugar therein. A plant for the manufacture of alcohol from sawdust includes an acid apparatus in which the necessary solution of the sulphurous acid gas in water is made, and where the gas when escaping from the boiler or digester is reabsorbed in the water, and thereby saved for further utilization; a revolving boiler or digester similar in construction to those used in making chemical pulp; an exhausting battery, consisting of a series of tanks through which water may

be passed, and in which the sugar that has been produced in the digester by the sulphurous acid gas may be washed out; neutralizing vats, in which the various acids in the solution are removed or neutralized by the addition of carbonate of lime; and finally, fermenting and still rooms, where the process is completed exactly as carried out in the ordinary distillery.

The sawdust is thoroughly mixed with the sulphurous acid gas and water, thus converting a portion of the cellulose into sugar. The sugar, of which about 85 per cent is fermentable, remains in the sawdust which is then introduced into the exhaustion tank. Here the sugar is simply washed out.

The digester or boiler in which the wood is first treated consists of a revolving drum of iron, lined with lead to resist the action of the acid, and surrounded with a steam jacket, by means of which it is heated. The drum is nearly filled with saw-dust. In the experimental plant one charge consisted of about 400 pounds of material. To this is added a weight of the acid solution equal to about one-third of that of the sawdust. The steam is turned into the jacket and the drum set to revolving slowly, in order thoroughly to mix the contents. The steam in the outside jacket heats the contents of the digester to a temperature of approximately 295 degrees Fahrenheit. The gas is driven out of the water in to the wood, so that it is caused to act directly on the cellulose, converting it into sugar.

The pressure inside the digester, due to the expansion of gas, rises to 100 pounds or more to the square inch. This part of the process lasts three hours.

The sulphurous acid gas and steam are then blown off from the cylinder into absorbing tanks in the acid room, where 75 to 80 per cent of the gas is saved, and may be used again. The digester and the surrounding steam jacket having been blown off, the cover is removed, and the digester is emptied of its contents, which now resemble ground coffee. The material contains the wood fibers and the converted cellulose, now sugar, and various other separated or partially separated products produced by the action of the acid and the heat on the wood. The process is not carried out as far as it is in pulp making, to which it bears some similarity. The object is to convert only as much of the cellulose into sugar as is practicable, and to bring the process to a stop short of a point where the sugar would be destroyed by a reversion.

The digester, while a somewhat crude arrangement mechanically, contains all the essential connections and accessories. Gauges are used for recording the steam pressure in the jacket and the pressure on the inside of the drum, and the temperature of the same. There are pipes for introducing the gas and the steam and blowoff pipes for the same.

In the experimental plant the exhaustion battery, as the outfit for washing the sugar from the sawdust is called, contains ten tubs or vats capacble of holding 36 gallons each. It may be said here that in the commercial plant, it is proposed to handle a long ton of dry sawdust at a time, and the digesters and exhaustion batteries will be proportioned according to the supply of sawdust or other finely divided wood. Sawdust is considered the best material, but particles of wood up to a quarter of an inch cube, or a quarter of an inch thickness, if in chip shape, appear

to be treated as successfully as the former. Each of the tubs in the exhaustion battery in a plant of commercial size would be enlarged to agree with the increased size of the digester.

These vats are so connected by pipes and valves with each other and with the pump, that the contents of any one tub can be emptied into any other. The principle of this part of the process is to bring the sawdust in contact with the solution already containing sugar, in order to make the solution as strong as possible, and further, to treat the nearly exhausted sawdust with pure water in order to complete the washing thoroughly. The process is continuous, and when the contents of a vat has been treated with ten washings, it is emptied out and refilled with fresh sawdust. Just before emptying, its charge receives fresh water, and after refilling, receives the strong sugar solution.

The result of this process is a solution which contains 450 to 500 pounds of sugar from a long ton of dry sawdust. This sugar is of two kinds; pentose, which is non-fermentable, and the other, amounting to 70 to 80 per cent, capable of alcoholic fermentation when treated with yeast. The solution from the exhaustion battery is pumped into the receiving tank, where it is neutralized with carbonated lime. This is necessary to prevent the acids, either the remains of the sulphurous acid, or certain acids derived from the wood itself from killing the yeast which is later added for the purpose of fermentation.

From this neutralizing tank this solution is pumped into a fermenting vat. To the solution, now called "mash", yeast is added. It is kept constant at the proper temperature, and fermentation commences in a very short time. When it is completed, the

product passes to the still room, equipped with still condensers, etc., As aforesaid, this part of the process is in no wise different from that ordinarily used in distilleries. The result is about 50 gallons of crude alcohol or 25 gallons of absolute alcohol from a long ton of sawdust.

The improvement in the output has been so constant that it is believed that in time the further development of the system will enable the manufacturer to obtain 30 gallons, and perhaps more, from a ton of sawdust; but the results obtained so far are quite sufficient to secure the entire approval of scientists and of practical men who are familiar with the manufacture and marketing of grain alcohol. Comparing the original cost of sawdust with that of grain, and the output of alcohol from the former with that from the latter, it seems that the new process is destined in time entirely to supersede the older one.

One of the most important features of the process is the utilization of the sawdust after leaving the exhaustion battery. While passing through the various stages of the process it contracts in volume from 25 to 33 per cent, while volume for volume its fuel value is apparently unchanged. As a matter of fact, apart from the cellulose which is removed, no other component having a fuel value has been taken out. If it is desired to use the sawdust as a fuel, it can accordingly be turned back to the mill and burned under the boilers after treatment, thus retaining the original intention. The residue, however, retains unchanged and practically undiminished in quantity such components as make it available for dry distillation. The treatment by heat and acid has left it dead

and without apparent elasticity. It can consequently be pressed
into briquettes without the use of a binder, and this is itself
an exceedingly valuable property.

The engine used in the following experiments was a stock
"R & V" engine with 4 3/8 inch bore and 5 1/2 inch stroke and
rated at 2 horse power at a speed of 335 revolutions per minute
and 100 pounds compression. Compression plates were screwed to
the piston to increase compression.

The fuel was measured by means of a tank and a float
carrying a pointer which traversed a calibrated scale located on
top of the tank. The tank was approximately 4 inches in
diameter and the calibration was obtained by pouring in the fuel
in 100 C.C. quantities. The pointer carried by the float indicat-
ing where the graduations were to be made.

The temperature of the cooling water was taken at its
entrance to and exit from the jacket and the quantity weighed.

The revolutions per minute and the number of explosions
were taken by actual count.

METHODS OF FIGURING RESULTS.
Brake Horse Power.

The brake horse power was obtained by the use of a Prony
brake and using the following formula:-

$$B.H.P. = \frac{2\pi.W.L.N.}{33000}$$

in which $\pi = 3.1416$, W = weight or pull on arm, L = length of
brake arm, in feet, and N = number of revolutions per minute.
$\frac{2\pi L}{33000}$ was constant for all the tests.

The number of revolutions per minute being 335 and 400 respectively, we can find a constant for each speed. These constants reduce the time of getting the results and are as follows:-

$$\frac{2 \pi L.N.}{33000} = \frac{6.28 \times 13\ 5/8 \times 335}{33000 \times 12} = .07238$$

$$\frac{2 \pi L.N.}{33000} = \frac{6.28 \times 13\ 5/8 \times 400}{33000 \times 12} = .0864$$

These constants multiplied by the load pulled at the given speed give the brake horse power.

CONSUMPTION.

The data obtained by the tests are in the terms of 100 C.C. consumed in a certain time when pulling a certain load. The results are better understood if given in the terms of "gallons per horse power per 10 hours."

100 C.C. equals a volume of 6.1 cubic inches,

10 hours equal 36000 seconds,

1 gallon equals 231 inches.

We now have the following formula:-

$$\frac{36000 \times 6.1}{231 \times H.P. \times time\ (in\ sec.)} = \frac{950.65}{H.P. \times time\ (in\ sec)} = \frac{Gallons\ per\ H.P.}{per\ 10\ Hrs.}$$

The 950.65 being a constant for all powers and speeds. It would not be difficult to derive a formula that could be used to obtain the consumption per horse power per 10 hours, directly

from the readings taken during the tests which are brake load,
speed and time to consume 100 C.C. of fuel. This would not give
the number of horse power pulled.

TABLE I.

Tests with Gasolene, 100# Compression.

Brake arm 13 5/8 inches.   R.P.M. = 335.

Brake Load Lbs.	H.P.	Average time for using 100 C.C.	Consumption gals. per H.P. per 10 hrs.
12	.868	7 min. 55 sec.	2.3
12	.868	8 " 3 "	2.26
18	1.3	6 min. 6 sec.	1.95
18	1.3	6 " 50 "	2.08
24	1.737	5 min. 3 sec.	1.8
24	1.737	5 " 11 "	1.75
30	2.17	4 min.59 sec.	1.46
30	2.17	4 " 44 "	1.52

TABLE II.

Test with gasolene, 100 lbs. compression.

Brake arm 13 5/8 inches.   R.P.M. – 400.

Brake load lbs.	Horse power	No. of explosions required	Average time for using 100 C.C.	Consumption gals. per H.P. per 10 hrs.
15	1.116	1 out of 3	6 min.	2.36 .
20	1.728	1 out of 2	5 min.	1.83
25	2.16	2 out of 3	4 min.	1.83
30	2.592	3 out of 4	3 min. 45 sec.	1.667
33	2.85	6 out of 7	3 min. 35 sec.	1.55
35	3.024	14 out of 15	3 min. 10 sec.	1.70

TABLE III.

Test with grain alcohol, 100 lbs. compression.

Brake arm 13 5/8 inches.   R.P.M. – 400.

15	1.116	1 out of 3	5 min. 4 sec.	2.80
20	1.728	1 out of 2	3 min. 30 sec.	2.62
25	2.16	2 out of 3	3 min. 10 sec.	2.31
30	2.592	4 out of 5	2 min. 55 sec.	1.94
33	2.85	6 out of 7	2 min. 37 sec.	2.10
35	3.024	19 out of 20	2 min. 20 sec.	2.24

TABLE IV.

Tests with grain alcohol, 100 lbs. compression.

Brake arm 13 5/8 inches.   R.P.M. - 335.

Brake load lbs.	Horse power	Average time for using 100 C.C.	Consumption gallons per H.P. per 10 hrs.
22	1.592	5 min. 15 sec.	1.89
22	1.592	5 min. 7 sec.	1.94
22	1.592	5 min. 2 sec.	1.95
28	2.026	4 min. 7 sec.	1.89
28	2.026	4 min. 8 sec.	1.89
28	2.026	4 min. 8 sec.	1.92
33	2.388	3 min. 50 sec.	1.73
33	2.388	3 min. 39 sec.	1.81

Table V.

Tests with grain alcohol, 105 lbs. compression.

Brake arm 13 5/8 inches.   R.P.M. - 335.

12	.868	6 min. 41 sec.	2.73
12	.868	6 min. 40 sec.	2.73
18	1.3	5 min. 25 sec.	2.25
18	1.3	5 min. 28 sec.	2.24
24	1.737	4 min. 23 sec.	2.08
24	1.737	4 min. 35 sec.	1.99
30	2.17	3 min. 52 sec.	1.88
30	2.17	3 min. 43 sec.	1.96

TABLE VI.

Tests with grain alcohol, 165 lbs. compression.

Brake arm 13 5/8 inches. R.P.M. - 335.

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Brake Load	Horse power	Average time for using 100 C.C.	Consumption gallons per H.P. per 10 hrs.
12	.868	6 min. 41 sec.	2.73
12	.868	6 " 28 "	2.76
18	1.3	5 min. 31 sec.	2.20
18	1.3	5 " 29 "	2.22
24	1.737	4 min. 46 sec.	1.93
24	1.737	4 " 36 "	1.98
30	2.17	3 min. 44 sec.	1.95
30	2.17	3 min. 42 "	1.94
33	2.38	3 min. 12 sec.	2.07

TABLE VII.

R.P.M.	Speed Comparison - Alcohol - 100 lbs. compression.			
400	25	2.16	3 min. 10 sec.	2.31
360	28	2.177	3 min. 35 sec.	2.03
335	28	2.026	4 min. 7 sec.	1.89

TABLE VIII.

Tests with unrefined sugar-cane alcohol-

130 lbs. compression.

Horse power pulled	No. of explosions	Gallons per H.P. per 10 hrs.
Average of 5 tests - 1.94	2 out of 3	2.17
" " " " - 2.42	5 out of 6	1.96
" " " " - 2.6	12 out of 13	1.92
" " " " - 2.72	19 out of 20	2.02

TABLE IX.

Tests with unrefined sugar-cane alcohol-
140 lbs. compression.

Horse power pulled	Gallons per H.P. per 10 hrs.
1.55	2.55
1.94	2.17
2.42	1.92

TABLE X.

Tests with unrefined sugar-cane alcohol-
185 lbs. compression.

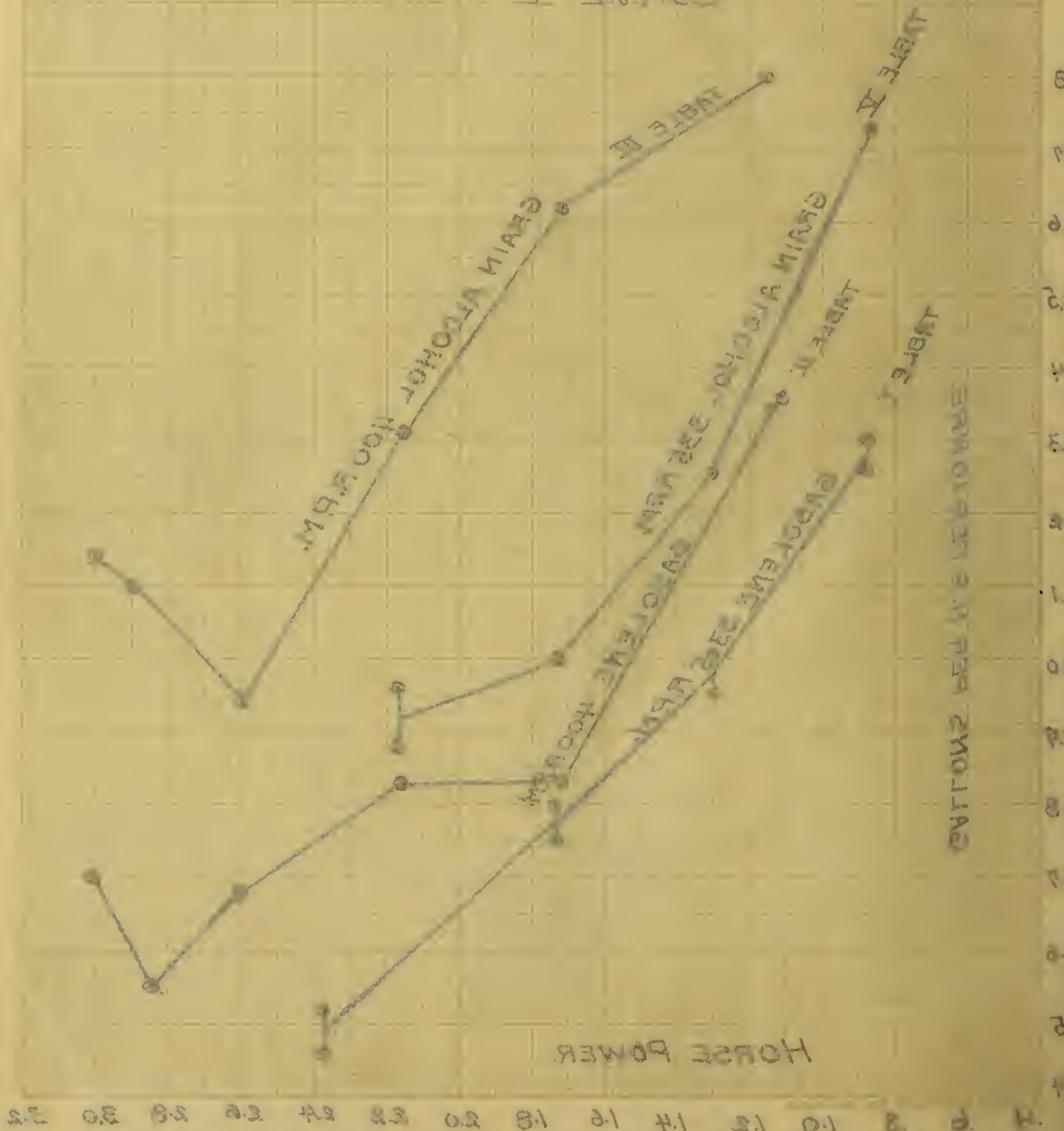| Horse power pulled	Gallons per H.P. per 10 hrs.
1.94	2.33

100 Pounds Compression

CURVE I

TABLE IV

TABLE III

GRAIN ALCOHOL 335 R.P.M.

GRAIN ALCOHOL 400 R.P.M.

TABLE II

TABLE I

GASOLENE 335 R.P.M.

GASOLENE 400 R.P.M.

GALLONS PER H.P. PER 10 HRS.

HORSE POWER.
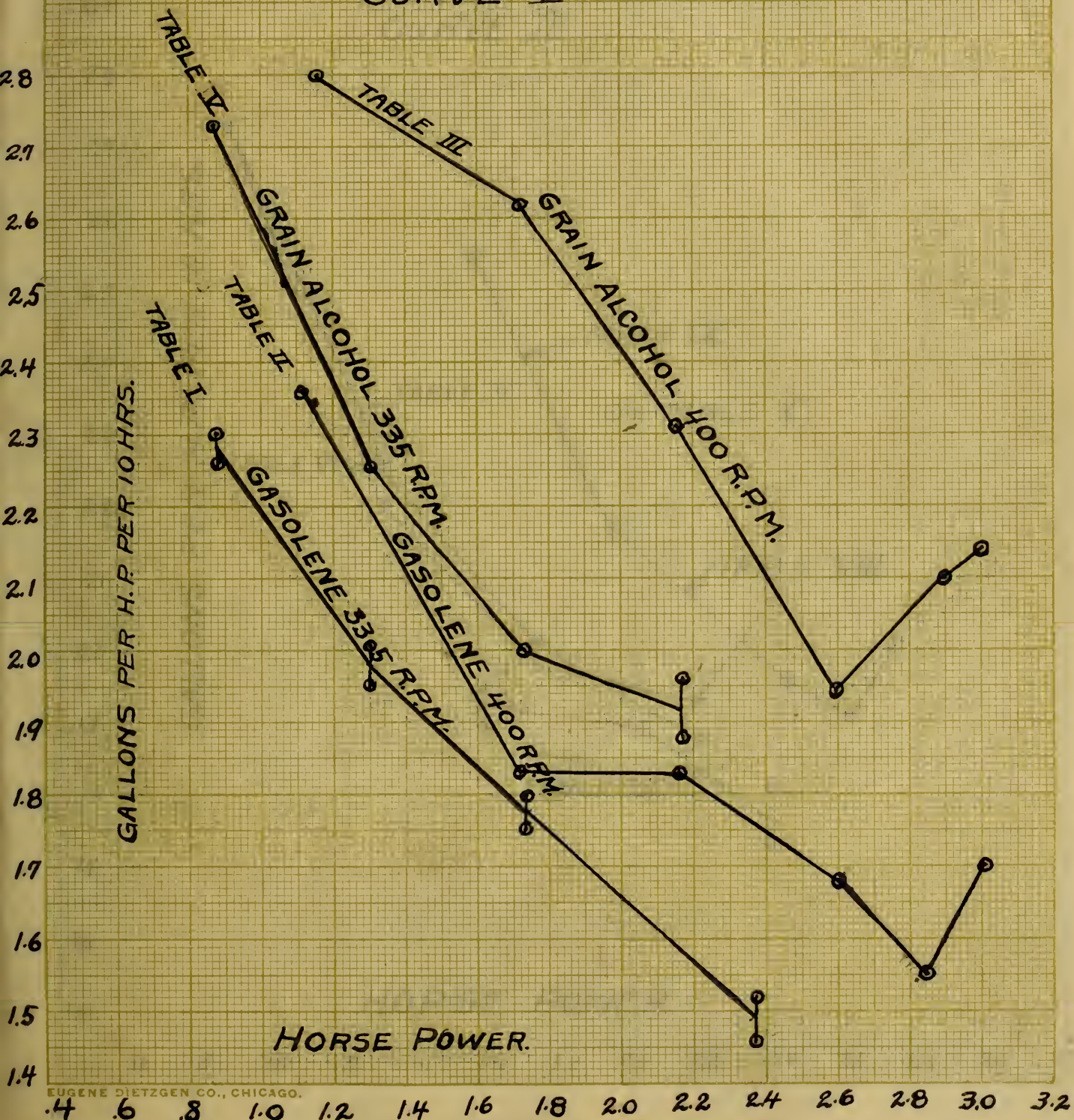
COMPARISON OF COMPRESSION

CURVE II

GALLONS PER H.P. PER 10 HRS.

HORSE POWER.

TABLE IX
TABLE V
TABLE VI
TABLE X
TABLE VIII
TABLE IV
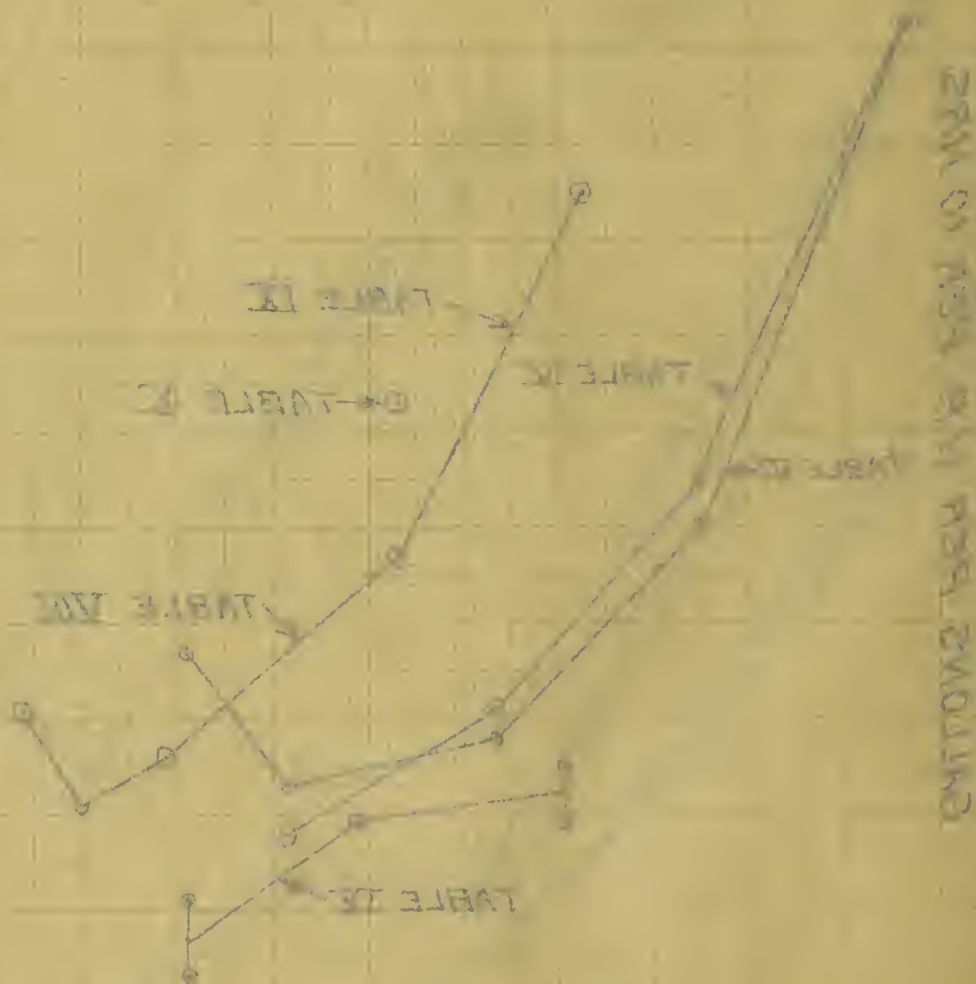
COMPARISON BETWEEN

SPEED AND CONSUMPTION

GRAIN ALCOHOL
100# COMPRESSION
TABLE VII

CURVE III

GALLONS PER H.P. PER 10 HRS.

SPEED — R.P.M.

2.40 2.35 2.30 2.25 2.20 2.15 2.10 2.05 2.00 1.95 1.90 1.85

310 320 330 340 350 360 370 380 390 400

COMPARISON BETWEEN

SPEED AND CONSUMPTION

GRAIN ALCOHOL
100° COMPRESSION
TABLE XII

CURVE III

SPEED — R.P.M.

CONSUMPTION — LBS. PER B.H.P. HR. ENGINE (A)

The graphical representation of the results of the various tests has proven very interesting. Curve I, page 38, shows the relation between consumption and horse power for gasolene and alcohol and at two different speeds. The general outline of the curves for both kinds of fuel at 335 revolutions per minute is very similar except that the consumption of alcohol is higher for the same power. The consumption per horse power per 10 hours decreases as the horse power increases. The curves for 400 R.P.M. are slightly different from the lower speed curves. The consumption and horse power are increased, but the curves show an increase in the consumption after 2.6 and 2.8 horse power for alcohol and gasolene respectively. The curves also show that the power and consumption increase with the speed faster with alcohol than with gasolene.

Curve II shows the results for the different compressions. Tables VIII and IX coincide. The best results in the way of economy were obtained in tables IV and V at 100 and 105 pounds compression respectively.

Table VII shows the increase in consumption per horse power per hour as the speed increases. These results plotted in curve III show that the consumption increases almost directly as the speed (power and compression remaining constant.)